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Detection of air leakage into vacuum packages using acoustic measurements and estimation of defect size

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ABSTRACT

Air leakages in food and ingredient packages which are sealed in vacuum environments may cause a marked deterioration of the product, leading to a loss of functionality. Manufacturers of such products have very stringent but rather costly quality control procedures and there is a pressing need for developing more economical ways of automated quality control techniques to test the vacuum packages reliably. However, due to the fact that the defect size of a typical package with a leakage problem could be micro- or nano-scale, such faults are not detectable using conventional techniques. In this paper, the performance of a proposed acoustic method is assessed for the detection of air leakage in instant dry yeast packages sealed in a vacuum environment, which are typical of food and ingredients packaged under vacuum conditions. The investigation is carried out in both laboratory and in-situ environments. The acoustic pressure created by leaking air into the faulty packages is measured using a low-noise microphone in an acoustic chamber. Faulty packages are then identified using the changes in measured sound pressure levels within a certain frequency band. A mathematical model is also proposed to predict the pressure inside a yeast package with certain defect size as a function of time. The mathematical model is then used to determine the size of a defect causing the leakage, using the time required for the pressure inside a faulty yeast package to reach to a threshold level. The results of this investigation show that, using the state of the art measurement techniques, it is possible to detect packages with leakage problem if the diameter of the defect is greater than a few tens of micrometres.

1. Introduction

Removing air from packages just before the sealing operation, which is known as vacuum packaging, is widely used in the food sector [1,2] to protect and to extend the shelf life of food products. Air leakages in those food packages, may cause a marked deterioration of the product, leading to a loss of functionality [3]. Manufacturers of such products have very stringent but rather costly quality control procedures to avoid yet more costly returns from their customers. There is a pressing need for developing routine automated quality control techniques to test the vacuum packages reliably and cheaply. However, due to the fact that the defect size of a typical package with a leakage problem could be micro- or nano-scale without any gas flow out of a package in the case of vacuum packaging, such faults are not detectable using conventional quality

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control techniques. Although the information about the fault sizes in a production line is quite valuable for optimising manufacturing processes, this information is not readily attainable via practical measurement methods. Furthermore, to the best of authors' knowledge, there is no available mathematical models for the prediction of air leakage into faulty vacuum packages containing ingredients.

There have been some studies for the detection of leakages in packages using the biotest [4] and ultrasonic imaging [5] techniques. However, these techniques are for evaluating the integrity of sample food packages and not suitable to detect the air leakages immediately after the packaging process at the end of the production line. Acoustic and vibration signals are also utilised for leak detection in some applications including leakages in pipes [6–10] which may cause huge economic losses. Both simulated and measured data are used in the literature to understand the mechanism of air leakage generation [11,12]. Furthermore, different signal processing techniques such as Short Time Fourier transform (STFT), Wavelet transform (WT), and Hilbert Huang transforms (HHT) are exploited to extract valuable information from acoustic signals propagating from a leakage [13–16]. A survey of literature on this subject reveals that most of the relevant studies in the literature are directed towards detecting leakages in pipelines, hence there is a real need for a practical technique capable of detecting air leakages in packages sealed in vacuum environment. In this paper, the detection of air leakages into yeast packages using acoustic measurements in an acoustic chamber is explored and a mathematical model is presented to estimate the amount of possible air leakages in faulty packages.

The faulty packages behave like an externally pressurised mechanical system which emits acoustic signal while air leaks into the system from very small-sized defects. It should be remembered that the defect size of a typical package with a leakage problem could be micro- or even nano-scale and the fraction of faulty packages in a typical yeast packaging line is very small. Therefore, it is decided to explore the sound propagated from faulty packages with known (artificially created) defect sizes in laboratory environment first. It is also aimed to develop a mathematical model for the prediction of the pressure inside a yeast package with a certain defect size as a function of time. Accordingly, the investigation in this paper is carried out using the following steps. (i) First, faulty packages with known defect sizes are artificially created and sound pressure generated by the leaking air into the package is measured in laboratory environment using a low-noise microphone and an acoustic chamber. (ii) The sound signals collected from packages with and without leakages are processed to detect the faulty packages. (iii) Then, a mathematical model based on sonic and subsonic flow is presented to predict the pressure inside a yeast package with certain defect sizes as a function of time. (iv) The mathematical model is used to establish a relationship between the time required for the pressure inside a faulty yeast package to reach to a threshold (detectable) level and the possible size of the defect causing the leakage. (v) Finally, in an attempt to detect the faulty packages, similar acoustic measurements are carried out in a factory environment at the end of the production line. The results of this investigation show that, using the current state of the art measurement techniques, it is possible to detect packages with leakage problem if the size of the defect is greater than a few tens of micrometres.

2. Test rig and measurement parameters

An acoustic chamber with interior dimensions of 300 mm × 450 mm × 500 mm is designed to measure the sound pressure generated by yeast packages with leakage problem. Although the details are not presented here for brevity, the acoustic chamber is designed to have high transmission loss level, compatible with the low noise microphone used in the measurements. Overall, the acoustic chamber has a few layers which are made of steel, lead and acoustic foam, with a total wall thickness of about 120 mm. The interior surface of the acoustic chamber is made of steel sheet to increase the reverberation effect inside the chamber. The transmission loss of the acoustic chamber is measured to be about 40 dB for the frequency range of interest (i.e., for 0.7 Hz–12.8 kHz).

A low-noise microphone with a sensitivity of 1211.6 mV/Pa (Brüel & Kjær Type 4955) is used to measure the sound pressure originated from leaking air into the faulty yeast packages. A picture showing a sample package and the microphone inside the acoustic chamber is presented in Fig. 1. The yeast packages are placed inside the chamber using three contact points so as to minimise the possibility of unpredictable sound generation due to macro- or micro-slip friction contacts. A high-precision data acquisition system (Brüel & Kjær Type 3050 A 040) is used to collect microphone data. For the in-situ measurements, the specially designed acoustic chamber mentioned above is positioned inside a larger acoustic chamber with interior dimensions of about 2 m × 2 m × 2 m. After a large number of preliminary trial tests, adequate measurement parameters are determined to be as listed in Table 1.

3. Laboratory simulations

The preliminary study, presented in this section, is aimed to assess the performance of the proposed method in the case of known defect sizes in laboratory environment. For this purpose, a micro-sized hole with different diameters is created on individual yeast packages to simulate a faulty package. Then, immediately after the fault is created, the faulty package is inserted inside the acoustic chamber shown in Fig. 1 and sound pressure measurements are made. Holes with specific diameters are created using some circular gauges (needles) with diameters of 450, 300, 200 and 150 μm. It should be stated that, using the tools available in these simulations, it was not possible to create a hole on a yeast package with a diameter less than 150 μm. Three sample packages are created for each fault diameter.